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The Effects of Visual Degradation on Attended Objects and the Ability to Process Unattended Objects within the Visual Array

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14. ABSTRACT
Previous studies have demonstrated different levels of processing for visual stimuli dependent upon whether the objects were attended to or not. This study consisted of two manipulations to further diagnose the processing of unattended objects. First, the attended object was visually degraded on some trials to determine if this would negatively influence the processing of unattended images. Second, the number of unattended objects within a trial was varied. Previous studies used one unattended object, while this study will use both one and three unattended objects within a trial. Although the degradation of the attended object did result in significantly longer reaction times in their naming, both degradation of the attended object and the amount of unattended objects did not influence the processing of unattended objects.

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Introduction

The visual array is typically cluttered with many objects of interest and disinterest; however, the human visual system can only process a very limited amount of this information at any particular moment of time. At times the entire scene may be processed with limited information devoted to individual objects, while other times attention may be devoted to a particular object, or even just a component within a particular object. This reflects the selectivity individuals use to process the visual information presented at any moment. The visual system does not recognize all objects in the visual field at once (e.g., Biederman, Blickle, Teitelbaum, & Klatsky, 1988), and objects of interest typically receive the attention required to recognize them.

However, previous work suggests that features of unattended objects are processed at limited levels (e.g., Treisman, 1985; Treisman & Gelade, 1980; Treisman & Gormican, 1988), and that certain stimuli presented outside of the visually attended to area (such as movement or flashing lights) appear distracting and can, at times, result in capturing attention. This suggests that visual processing occurs throughout the visual array, but it is not yet known how much processing is accomplished for unattended objects.

Differences in processing of attended and unattended objects

Previous works have attempted to determine the differences in visual processing found between attended and unattended objects. Via priming paradigms, research demonstrates that both attended and unattended objects are processed and to an extent recognized despite image location changes within the visual field (Biederman & Cooper, 1991) and image size changes (Biederman & Cooper, 1992). Yet, only attended objects are recognized when mirror images (left-right reversals) occur (Biederman & Cooper, 1991). Due to these results, Hummel (2001) proposed that attended images are processed by both viewpoint-invariant-models of object recognition (typically described as structural descriptions, e.g., Biederman, 1987; Hummel & Biederman, 1992; Marr & Nishihare, 1978) and viewpoint-dependent-models of object recognition (typically described as image based descriptions, e.g., Bülthoff & Edelman, 1992; Edelman & Intrator, 2003; Tarr & Bülthoff, 1995). However, unattended images are processed via viewpoint-dependent-models of object recognition exclusively, and therefore mirror images of unattended objects are not recognized. The idea of viewpoint-based-only processing for unattended objects is also supported by research demonstrating that attended split images are processed, but unattended split images are not processed (Thoma, Hummel, & Davidoff, 2004). Although attention appears to create a more complete representation of an object, there is no denying that unattended objects are processed to some level.

Of interest in this study are the limitations of resources used in processing unattended objects, not the depth at which unattended objects are processed. The previous priming studies mentioned above always used two objects, one which was attended and named, while the other one was ignored. This created an environment with few objects in the visual array, but required complete processing of the objects at a categorical level of recognition. The opposite approach was taken in feature integration theory (see Treisman & Gelade, 1980), which argues that feature maps exist and are retinotopically organized in relation to visual locations. Feature maps detect specific features only (e.g., the color red or vertical lines), but the features of different maps are not put together without a process referred to as binding, which requires attention. Studies supporting feature integration theory use several distracters and reveal pop out or serial search performance in different visual search tasks. Pop out performance requires distinctly different features to exist for the target from the distracters, but does not require complete recognition of the objects in the visual array (typically a subject is asked to find an object, not to identify one or all objects). Serial search is present when the target cannot be discriminated from the distracters and thus binding must take place to separate the target from distracters.

This experiment was designed to answer if multiple unattended objects could be processed at once and demonstrate priming effects. To address this concern, either one or three unattended objects were presented during a given trial (for a total of two or four objects, since one was attended on every trial). Two possible conclusions could result from this study. The first is that the study may find priming for when one unattended object was present, but not for the presentation of three unattended objects. This would suggest that the processing of unattended objects is extremely limited and that the priming of unattended objects may be only possible in rare conditions, such as when limited resources typically used to process the visual array are not overtaxed. These instances may allow enough resources to be free to process both the attended object and one (or very few) unattended object. The second possible result of this study may find priming for when three unattended objects were presented. This could suggest that a very small limit for processing unattended objects does not exist which provides evidence that further research is warranted to test the limits of processing unattended objects.

An additional interest addressed in this study was the effects of the limited resources used to process the attended object, and if they possibly restricted the processing of unattended objects. To address whether the processing of the attended object influenced the processing of the unattended objects, a visual degradation of the attended object was conducted. If degradation of the attended object resulted in slower naming times than their non-degraded counterparts, then it would appear that participants had a more difficult time naming the attended object when degraded. This requirement of additional resources to name the object when degraded may result in a negative affect for the processing of unattended objects. This would be what one would expect if one cognitive mechanism processed both attended and unattended objects. However, if the degradation of attended objects did not result in more attentional demands, and did not negatively influence processing of unattended objects, then it could suggest that two different cognitive mechanisms may exist for processing visual information; one for processing attended and one for processing unattended objects. The two different cognitive mechanisms may result in different levels of processing, which could explain why attended objects are processed more as suggested by previously discussed priming articles. If the results of this study did suggest that two cognitive mechanisms existed for processing objects, it would warrant more studies in order to further tease apart two things: 1) if in fact two different cognitive mechanisms do exist and 2) what are the limits of visual processing for each cognitive mechanism.

Military relevance

The head-up display (HUD) is a critical component of flight, providing a projection of symbology into the pilot’s direct field of view. This direct presentation of visual information enables the pilot to monitor both instrumentation and the outside world at the same time, as opposed to looking away from the outside view to read instrumentation (similar to looking down to the instruments of one's car while driving, referred to as head-down displays, or HDD). In 1960, the Hawker Siddeley Buccaneer jet aircraft included the first operational HUD used by pilots for flight (Weintraub & Ensing, 1992). Since then, the display has been altered, but the original display provides the basis for the HUDs of today.

Aside from assisting in landing situations with lower visibility, HUDs have demonstrated advantages over traditional HDDs in such realms as maintenance of flight path and landings (e.g., Fischer, Haines, & Price, 1980; Naish, 1964). Not only has this led to cost savings, but flight is safer due to the information provided to pilots, especially at critical times such as takeoffs and landings. However, deficits have been found to exist in pilot performance due to the presence of the HUD.

Allocation of attention to both the outside world from the view of the cockpit and the represented world presented in the HUD would benefit the pilot's performance. For example, instead of looking down to read instruments (which even a few seconds results in a great distance being covered), pilots can view flight information without sacrificing their view of the outside world. However, attention is a limited resource as discussed above, and individuals are better at detecting events in the environment when they correspond to where their attention is focused (Wickens & Hollands, 2000). It appears that at any given time, pilots can only attend to either the HUD or the outside world no matter how closely related the two are. In situations where the HUD has been relied upon for a particular task (e.g., landing due to low visibility), elements of the real world may be more difficult to detect, slowing down normal response times to given situations (McCann, Lynch, Foyle, & Johnston, 1993; Moodi, 1995). This delay in response to the outside world situation has suggested that attending to the HUD prevents processing of outside information.

Ververs and Wickens (1998) found that the nature of the task and the nature of the display could influence an individual's ability to divide their attention. However, the same study also found that features which assisted in dividing an individual's attention may also inhibit their ability to focus attention on specific aspect details. HUDs have relied upon presenting visual symbology directly in front of the pilot's field of view, where it can be directly interpreted but may capture attention and sacrifice processing of the outside world. This capturing of attention is referred to as attentional trap. As technology advances, more information may be presented via a HUD, such as, telephone wire detection for helicopter pilots. Further visual information would then be presented to the pilot, which may result in a further dependence on the HUD, and thus led to increases in situations of attentional trap.

The solution to this may not be limiting the information presented via the HUD, but perhaps in finding ways to present information to the pilot that do not capture attention. Non-critical information may best be presented in the peripherals, especially if it can be interpreted by the pilot, even if below the conscious level. Research concerned with processing of unattended visual information may be a solution to finding new ways to present information via the HUD without causing distractions to the pilot's overall situational awareness. Although previous research has not yet suggested this, demonstration of overall processing of unattended visual objects is an early step needed to determine the limits that unattended objects may be processed.

Following this, studies can further test the limits of what is or is not processed when unattended and new presentation and symbology can be created in HUDs to present this information.

The current study seeks to investigate the visual system's ability to process unattended images with variations of visual degradation to the attended image. The findings of this study may result in influences to the designs of visual displays allowing individuals to process new information while not sacrificing attention to critical information elsewhere. This would allow more information to be presented to the individual without leading to further distractions from the outside world.

Methods

Participants

The participants were 48, 19 to 40 year old native English speakers with confirmed normal or corrected-to-normal vision. Participants received no compensation for their participation in the study and were recruited from the Fort Rucker, Alabama population. Participants were both civilians and Soldiers, with no statistical tests conducted to determine mean differences in performance between the populations.

Screening measures

Each participant was required to complete a survey (see Appendix) to determine if they were at their normal level of alertness for the time of day they were tested. This would allow the researchers to review participant's results and determine if those who were below their normal alertness level were able to do the study. The survey asked about current prescription drug use and both current caffeine intake for the day and their routine caffeine intake. Three participants stated that they were below their normal caffeine level for that time of the day; whereas four participants were taking current medication which could lead to fatigue or drowsiness (one participant met both criteria). A visual inspection of the data from these six participants demonstrated no major differences in their data from the rest of the group. No participants were removed from the study due to their current alertness level, and no further analyses were conducted concerning the results of the survey.

After completing the survey, participants were tested on the Humphrey 599 auto-refractor, which provided immediate feedback on eye-refractor abilities and any possible visual deficits, which could be corrected by contact lenses or glasses of a particular prescription. Each individual with a poor score on the auto-refractor had corrected vision (three participants). No participants were excluded based on the results of the auto-refractor.

As a final test of visual acuity, participants read a string of letters presented on the computer screen. The letters were 2 millimeters (mm) tall, and the participant sat approximately 50 centimeters (cm) from the screen, thus each letter was approximately 0.23° in visual angle. Participants read three presentations of ten letters. The first presentation was read with both eyes open, the second with only their left eye open, and the third with only their right eye open. For each presentation, participants were required to get at least nine of the letters correct to be allowed to participate in the study. All participants met this requirement.

Stimuli

Each picture was a colored and shaded object altered from Rossion and Pourtois' (2004) catalogue of common objects or animals that could be easily distinguished with a basic level name. Although 250 objects were presented during the actual study, only 192 of these objects were named while all other objects were distracters. The 192 objects that were named were selected by a norming survey conducted prior to this study. All named objects were scored as easy to recognize, with an average score of above 5 on a rating scale of 1 (very difficult to recognize) to 7 (very easy to recognize), and were not thin objects that would have been made very difficult to recognize by the process of degradation described below (such as a pencil or screwdriver). The objects measured no more than approximately 6 cm horizontally or vertically on the screen. Participants were seated at a comfortable distance (approximately 50 cm from the screen). From this distance, the visual angle of the largest objects was approximately 6.87°, and all objects were centered approximately 7.72° from the participant's fixation point.

For the visual degradation of the objects, three patterns of "white" lines were created using Adobe Photoshop. All lines were approximately 5 mm thick and were displayed diagonally from the upper right to the lower left. Each visual degradation condition consisted of a different amount of lines obstructing the object. The low degradation consisted of three lines, the medium degradation consisted of four lines, and the high degradation consisted of five lines. These patterns were placed over the objects so that the white lines occluded portions of the objects. All patterns were created to be the same size as the objects so that each pattern overlapped each object in a similar fashion. Figure 1 shows an example of medium level degradation.

Figure 1. Example of stimuli used in the study.

Equipment

An IBM Dell Latitude D830 Laptop computer with a 2.40 gigahertz processor and a refresh rate of 60 hertz was used. Objects were presented using the E-Prime Professional 2.0 program from Psychology Software Tools. Psychology Software Tools' button box and microphone were used to capture the timing of the participant's naming of each object, and all data were recorded by the E-Prime program to an electronic format.

The study was conducted in a relatively quiet portion of the lab and used an audiometric booth to create an overall quiet environment. This assured that the microphone could be calibrated at a comfortable speaking level for the participant and would reduce the microphone from picking up any external noises from the lab environment.

Procedure

The procedure used for this study was similar to that used by Biederman and Cooper (1991). For a pictorial representation of a trial from this study, see figure 2 (all slide references here refer to figure 2). Each trial began with a presentation of a fixation cross to center the participant's attention (slide 1) which was presented for 495 milliseconds (ms). The participant was instructed to focus on the fixation cross until the cue was given for the prime object. Slide 2 was a presentation of a cue (in the form of a box) indicating where the participant should attend and which target location should be named. The cue was presented in the form of a 5 x 5 cm box presented in either the upper left, upper right, lower left, or lower right part of the screen for 75-ms, with the box centered approximately 7.72° from the center of the fixation cross. Immediately following the cue, two or four priming objects were presented in the same possible locations of the cues for 120 ms (slide 3), followed by a 30 ms presentation of a blank screen, and then a visual mask was presented until the participant made a response (slide 4). The time from the onset of the cue and the complete presentation of the priming objects (195 ms) was designed to be too fast for executed eye movements toward the cued primed object (250 ms), which assured that all objects fell equally within the central region of fixation. The participant's task was to name the prime object where the cue had been presented as fast and accurately as possible. A microphone was used to register the participant's response which measured the time from object presentation to first vocal sound of the participant. Participants were asked not to say anything prior to naming the object and any trial in which the participant did make a sound prior to naming the object was counted as an error. After naming the prime object, slide 5 (an additional fixation cross) was presented to refocus the participant's attention to the center of the screen, followed by the probe image presented in slide 6. The probe image presented in the center of the screen for 120 ms and was either A) the original attended target from slide 3, B) an unattended target from slide 3, or C) a new target (one never viewed before), followed by another mask until the probe image was named. The researcher pressed a key on the button box to initiate each trial. After the probe object was named, the names of the correct prime and probe objects were presented on the screen along with the reaction time of the response to probe object. When the participant indicated he or she was ready, the researcher pressed one of four buttons to proceed.

Researchers coded responses by pressing one of four buttons which indicated the accuracy of the participant's responses: either both responses were correct, error on prime object, error on probe object, or error on both objects. A response was considered correct if it fell within a similar category (e.g., calling a fox a dog was counted as correct), and most errors were due to the participant not being able to name the object or due to making a sound prior to naming the object (both cases were rare though). To assure the accuracy of the responses during the study, both a journal was kept during the study for researchers to log trials in which they think they pressed the incorrect button, and a tape recording of participant's responses was created and reviewed by the primary researcher.

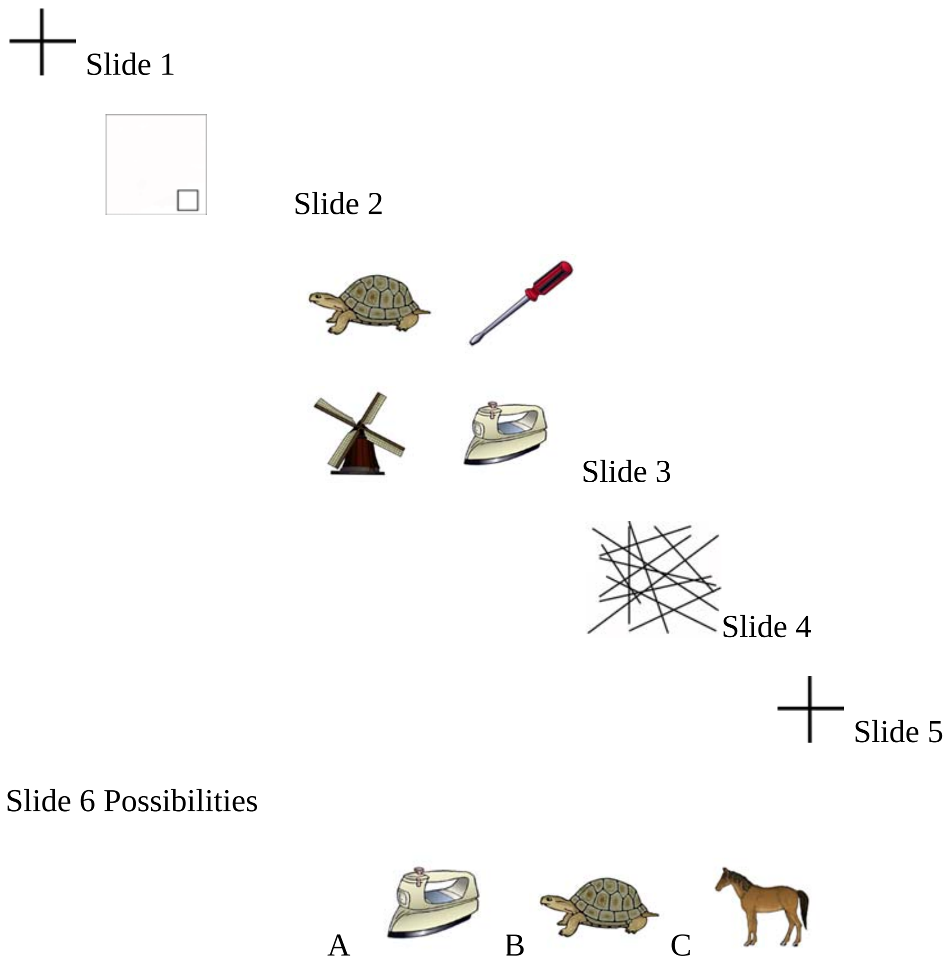

Figure 2. Pictorial example of one trial. Objects are not shown in proper size.

Prior to the beginning of the study, 12 practice trials were conducted to assure that the participant understood the task and to make sure they did not make other noises loud enough to elicit a microphone response. The 12 practice trials used objects not presented in the study. All objects that were used as prime or probe objects were used in only one trial, while distracter objects were used multiple times. A total of 96 trials were conducted and the entire experiment lasted approximately 30 to 45 minutes. Participants were allowed to take as many breaks as they needed while participating in the study, and a mandatory 5 minute break was taken at the halfway point to prevent fatigue, eye strain, and headaches.

Figure 3. Example of prime stimuli. Objects are not shown in proper size.

Design

Due to the limited number of objects available (260) and a desire not to repeat named objects, a total of 96 trials were conducted. Participants were assigned to one of eight groups by order in which they were run in the study. The differences between the groups existed only to indicate individual trials that may have had unusual characteristics (e.g., an unfortunate unforeseen pairing that could have resulted in priming due to a semantic priming effect[1]). In order to determine a problem trial, each trial was run with two possible attended objects. That is, in figure 3, half of the participants viewed the iron as the attended object, while the other half viewed the windmill as the attended object. The attended object in figure 3 would be the iron which in this scenario was visually degraded and thus should be harder to process. If processing of attended and unattended objects is conducted by the same cognitive mechanism with limited resources, this should limit processing of the unattended object, and would be evident by a lack of priming for the unattended object.

Along with this, the amount of the visual degradation of the attended object was varied by groups.[2] One quarter of the time this particular trial had no visual degradation on the attended object, one quarter had low visual degradation on the attended object, one quarter had medium visual degradation on the attended object, and the last quarter had high visual degradation on the attended object. These eight different scenarios were used to indicate if any objects were processed more completely than others. That is, individuals may have just processed windmills well, regardless of whether the windmill was attended to or not, or despite the different levels of

[1] Semantic priming effects are those in which an association or relationship between the items leads to priming. That is, having viewed a baseball bat, one would be primed for objects of a baseball, a baseball glove, or a baseball cap because of the close associations the items have with each other.

[2] Only the attended object was degraded.

visual degradation to the object of the windmill. Evidence of this would be a constant response time for this trial across all conditions.[3]

Data analysis

Two separate analyses were conducted on the data. The first was a one-way, within subjects ANOVA on the reaction time to naming the attended prime object. The ANOVA was conducted with four levels, which were determined as the different levels of degradation to the attended prime object; none, low, medium, or high. The second analysis was a 2 x 3 x 4 repeated measures ANOVA. The three conditions were number of items (two or four) presented in the prime, the type of probe (the attended object in the prime presentation, an unattended object in the prime presentation, or a novel object), and the degradation of the attended object (none, low, medium, or high). For all significance tests, an alpha of 0.05 was set for results to be significantly different.

Results

Prior to including a participant's data for analysis, four criteria needed to be met. The first was having normal or above normal vision for the task. This was tested in two measures, with the auto-refractor and the vision test. Of those who demonstrated visual deficiencies from the results of the auto-refractor, all wore glasses which corrected their vision (three participants). To pass the vision test, participants had to correctly read 9 of 10 letters in all three conditions (left eye only, right eye only, and both eyes), which all participants were able to do. The second criterion concerned the possibility that the individual's alertness level may have influenced their results. Participants at a possible lower alertness level than normal had their data visually analyzed to see if their results differed from other participants. None of the participants who reported possible lower attention levels from the survey demonstrated results that were different from the other participants. Therefore, the survey results did not exclude any participants. The third criterion was their overall missed trials. Any individual who had more than 10% of their trials excluded (10 or more trials) were not used in the results of this study, which excluded one individual. Finally, participants who missed more than one trial within a set level were excluded due to the fact of the relatively few trials used in the experiment, and that many different conditions were used, which resulted in only four trials for each particular level. Three participants were excluded from the results due to the final criterion. Based on the established criteria, four participants were excluded from the analysis (N = 44).

Analysis of prime object reaction times

A one-way ANOVA was conducted on the reaction times for naming the attended prime object. The ANOVA resulted in a significant main effect for visual degradation [$F(3, 129) = 9.404$, $p < 0.001$] (figure 4 displays the means). Post-hoc Bonferroni corrected pairwise comparisons were conducted for the levels of visual degradation and revealed that high visual degradation resulted in significantly slower reaction times than low and no visual degradation, *p*

[3] There was no evidence that any objects were named faster than other objects, that visual degradation did not affect certain objects, or that semantic priming took place in any of the pairings used for this study.

= 0.001 and $p = 0.002$, respectively, and medium degradation led to significantly slower reaction times than low visual degradation, but not when there was no visual degradation, $p = 0.013$ and $p = 0.062$, respectively.

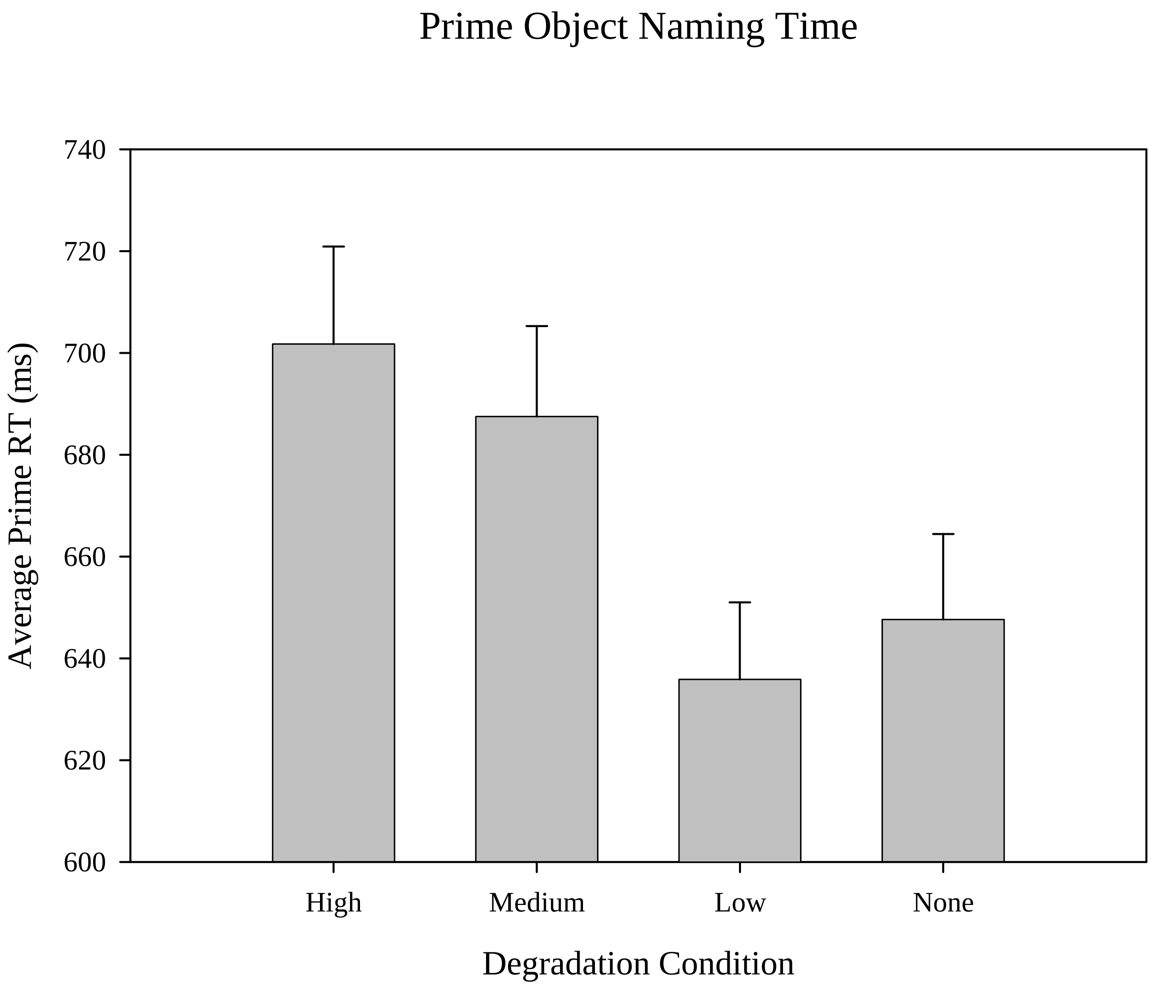

Figure 4. Graph of prime object naming time. Error bars represent the standard error of the mean for reaction time performance.

Analysis of probe object reaction times

A 2 x 3 x 4 within subjects repeated measures ANOVA was conducted on the reaction times for naming the probe object. The ANOVA determined a significant main effect for the type of probe [$F(2, 86) = 156.8$, $p < 0.001$], but the number of unattended prime items ($p = 0.537$) and the degradation of the prime object ($p = 0.352$) did not result in any significant differences in reaction time, and no interactions between the conditions were significantly different (figure 5 displays the means). Post-hoc Bonferroni corrected pairwise comparisons were conducted for the levels of type of probe. The analysis revealed significant differences between all levels, with attended objects named fastest, and new objects named slowest. All *p* values were less than 0.001.

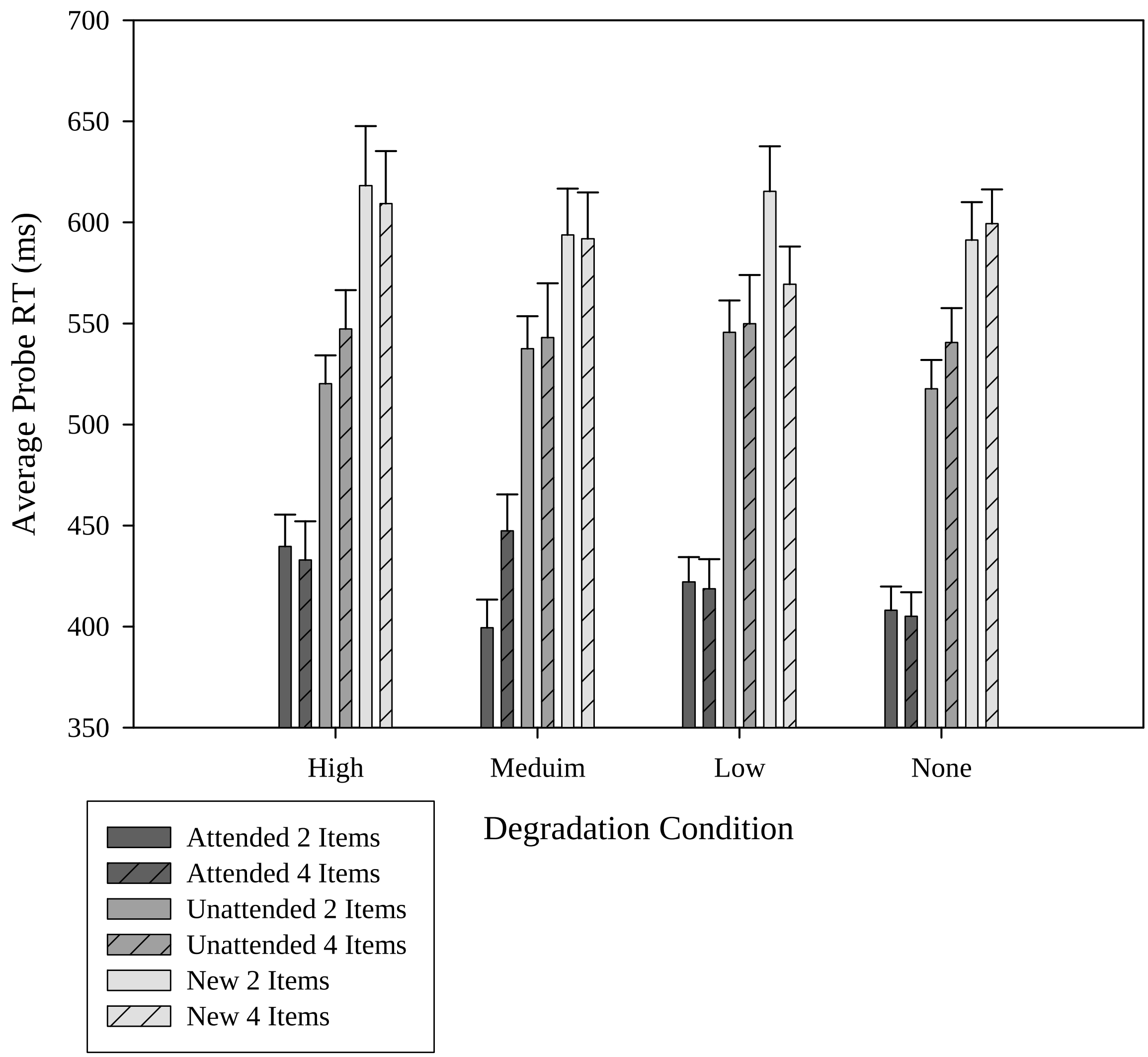

Figure 5. Graph of probe object naming time. Error bars represent the standard error of the mean for reaction time performance.

Discussion

The amount of visual degradation to the attended prime object was used to establish whether or not we could begin to determine if attended and unattended objects are processed by the same cognitive mechanism. More degradation to the attended object resulted in slower naming times for the prime image. This suggests that the degradation of the attended object resulted in a condition that was more difficult to recognize, and thus required more processing. The idea that the degradation of an object leads to a more difficult task of recognition is not novel, however what is novel and of interest in this experiment is how this additional need for resources to process that attended object would influence the ability to recognize unattended images.

The type of probe demonstrated that both attended and unattended objects were processed during prime presentations, and were both named faster than new objects. This demonstrates that the visual system is able to process unattended images at some level even if it is below conscious recognition (pilot studies demonstrated that individuals could not name all four images presented in this study's format). The findings here are similar to what has already been established in the introduction of this paper. However, replication of these findings was necessary to establish the additional parts of the experiment.

The results of the probe naming times suggest that the level of degradation to the attended object did not influence the processing of unattended objects, since naming times for probe objects were not significantly influenced by prime object degradation levels. This could suggest one of two processes is taking place. First, it could suggest that one cognitive mechanism processes both attended and unattended images and that the task used in this study did not overload the system. If one cognitive mechanism is used to process both attended and unattended objects, it should be possible to tax the cognitive mechanism enough so that degradation to the attended object would negatively affect processing of unattended objects. However, the results of this study may more likely indicate that two different cognitive mechanisms exist, one to process attended objects, the other to process unattended objects. If this were so, then despite any levels of degradation to the attended object, unattended objects would still be processed in a limited way. Future presentations of information then could take advantage of the limited processing of unattended objects to assist the visual system with more information without taking away resources to what the visual system is currently attending to. Although this information may be extremely limited, it is one untapped way to present information.

The probe naming times also looked at the number of unattended objects presented during the prime presentation (either one or three). The number of unattended objects did not significantly influence the naming times of the probe stimuli for any of the type of probe conditions. This again could suggest one or two cognitive mechanism processing the objects, with at least the resources to process three unattended objects. However, if two cognitive mechanisms do exist, the one processing unattended objects may sacrifice high detail to process several objects. That is, the visual system could be divided into two cognitive mechanisms, the first processes one object in extreme detail (the attended object), and the other may process several objects but in very low detail. This may explain why unattended objects are processed only in a limited fashion, and may explain why attention is so limited. Further studies are needed though to further test this idea.

Study limitations

While previous researchers have studied the differences in levels of processing between attended and unattended objects (e.g. Treisman & Gelade, 1980; Hummel, 2001), this study focused on the possibility of shared or independent resources used to process objects. The results suggest that attended and unattended objects may be processed via independent resources, but further studies are still needed to further explore this. The visual environment used for this study was very simple compared to the real world. The environment in the study existed of up to four objects at one time, with attention levels only manipulated by a degradation of the attended object. One cognitive mechanism could be processing all of the objects presented on the screen at one time, and this study may have failed to tax that cognitive mechanism enough to demonstrate a detriment to performance. However, adding additional objects in the presentation may not be practical as objects may begin to appear more cluttered in the presentation (although that is similar to many real world situations). This could result in the wrong object being attended to. Also, the degradation of the attended object does result in the need for more attention, but may not be accurate in the attention given to HUD instruments (e.g., the vernier acuity task required for level flight using the HUD). Attention can be allocated for several different reasons, and each reason may limit the processing of unattended objects. Understanding the limitations of processing unattended objects due to different circumstances is critical to evaluate the effectiveness of this presentation of information. Future tasks should focus on more 'realistic' situations, such as during a simulated flight.

Future considerations

The future implications of independent cognitive mechanisms processing attended and unattended objects would influence future HUD designs, along with future training of Soldiers. As HUDs increase in popularity in roles besides those of pilots, future technology must take advantage of ways to process the most information. The potential information that could be portrayed in visual representations may be vast, but the human visual system is limited in the amount of processing. Unless ways are created to assist with the limits of the human component, future designs of visual displays will remain limited in the amount of information that can be processed by the individual, and displays will continue to capture attention at critical times which may result in an overall loss of situational awareness.

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Appendix

Medication and Caffeine Consumption Questionnaire

Participant Number _______________

Are you currently taking any medications? ______________

If you are on any medications, please list them on the lines below. If you are not on any medications, please mark NA below.

On a typical day, how much caffeine do you consume? Please list typical beverages and how many you consume a day. Example "one can of Coke" or "two cups of coffee." Please be as accurate as possible.

Today, how much caffeine have you consumed?

Is this amount typical for you at this time of day?

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